fruitful to suggest the possible practical use of these magnesian clays in cases in which a tight tamping is necessary where water has access, as in shutting off crevices in bored wells when, as in those yielding oil, undesirable flows of water interfere, and where tamping with ordinary clays fails to tighten sufficiently and permanently. Other uses for such a prodigiously swelling material readily suggest themselves.

STUDIES OF MAGNITUDES IN STAR CLUSTERS, I. ON THE ABSORPTION OF LIGHT IN SPACE

By Harlow Shapley

MOUNT WILSON SOLAR OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

Received by the Academy, November 17, 1915

All researches on the structure of the stellar universe must take into account the probable and possible effects of the scattering or obstruction of light in its passage through interstellar space. It is recognized, for instance, that if the loss due to absorption, or scattering, by the free molecules of matter in space totals as much as a millionth of one per cent of the visual light in a journey of a hundred million miles, then, assuming the effect proportional to the distance, every star 3500 light-years away would be observed about two magnitudes fainter than its true brightness. As a consequence any uncertainty in the coefficient of scattering, especially if it is large as cited above, is very serious in studies of the distance of the faint stars and particularly in considerations of the stellar densities in various parts of the galactic system. In fact, the hypothesis that light extinction is imperceptible is prerequisite to the conclusion that the stellar universe is finite in extent.

Because of the importance of the subject several extensive investigations have been undertaken in recent years for the purpose of determining the amount of absorption. It is generally assumed that if any dimming of a star occurs it will be apparent as selective molecular scattering, which varies as the inverse fourth power of the wave length of the light.

As the effect for blue light would be about double that for yellow, an obvious method of detecting and measuring selective absorption is through the study of the colors of faint and distant stars. By means of measures of color indices various investigators have found that the fainter stars are on the average redder than the brighter ones, and as the fainter stars are also on the average, the more distant, this excess of redness might be and often is accepted as an indication of space absorption. There are, however, other possible interpretations, including the effect of

intrinsic luminosity on color and the possibility of the predominance of redder spectral types among the faint stars and the more distant ones.

In all previous special studies of the problem, the chief difficulties have been the uncertainty of the distances (so few of which have been directly measured) and their relatively small values. For a given spectral type the observed color excess of the more distant stars is also small. Consequently, though positive values for the absorption coefficient have always been derived, they have in no case been considered as definitely final proof of the existence of an appreciable space absorption. The four most recent determinations (all of which depend upon studies of the colors of relatively nearby stars) give the following values for the increase of the color index for each unit of distance (32.6 light-years):

Observer	King	Kapteyn	Jones	Van Rhijn
Absorption coefficient	0.019	0.0031	0.0047	0.0015 mag.

Since the color effect is cumulative, an increase in the length of the base line increases greatly the accuracy of a measurement of absorption. If instead of using stars in our immediate stellar system, we extend the study of colors to much more distant objects, then we can readily decide whether light scattering is to play an important part in stellar investigations. The advantage of great distances is taken in the present study of globular clusters, and already it is possible to make a definite contribution to the problem of the existence of light scattering.

At the beginning of a systematic study of magnitudes and colors of stars in clusters, the great globular system in Hercules, Messier 13, has been observed photographically, both with ordinary plates sensitive to blue and violet light and with isochromatic plates which respond chiefly to the most effective visual light when the shorter wave-lengths are cut off by means of a yellow color filter. Photographic and photovisual magnitudes for about 1300 stars have been determined. The color indices thus secured are compared with those for nearby stars with identical spectra (whenever the spectra of the cluster stars can be directly observed), and the excess of redness for the cluster stars indicates the amount of space absorption. When the spectra can not be directly observed the color indices in the cluster still may serve to solve the problem. For, if the stars in the distant cluster are even approximately similar to those near the sun, the absolute values of the color indices will tell at once whether there is practically no absorption or whether there is a really appreciable amount.

The detailed discussion of the magnitudes in Messier 13, which will appear as a *Contribution from the Mount Wilson Solar Observatory*, will

include a consideration of the reliability of the magnitudes and color indices and an extended analysis of the observational data. For the present communication a part of the results bearing on the absorption of light in space are shown in a condensed form in the following table. The magnitudes of the stars in the denser regions of the cluster, within 2′ of the center, are omitted, as none of the polar standards upon which the determination of the magnitude is based falls within that area, and consequently no control of the possible systematic errors of a photographic nature is assured. The color class has been defined in the September, 1915, number of these PROCEEDINGS; in brief we may say that, under the average conditions of luminosity and distance that obtain for the brighter nearby stars, color class and spectral class are practically identical, but if considerable absorption exists the two do not correspond for more distant objects, redder color being associated with bluer spectrum.

Frequency of Colors in Messier 13—Number of Stars Tabulated

DISTANCE FROM CENTER OF CLUSTER	COLOR CLASS									
	b0 to b5	b5 to a0	a0 to a5	a5 to f0	f0 to f5	f5 to g0	g0 to g5	g5 to k0	k0 to k5	k5 to m0
2′ to 3′	7	39	10	16	20	50	50	17	5	1
3′ to 5′	8	20	21	7	23	59	44	9	4	2
>5′	1	11	5	4	7	26	21	7	0	1
Totals.........	16	70	36	27	50	135	115	33	9	4

The most remarkable feature of the distribution of color class exhibited in the table is not the relative paucity of *a*'s and early *f*'s, nor the great range in color, but rather the highly significant fact that there are any negative color indices (*b*0–*b*9). Of the 495 stars more than 17 % are of color class *b*, and of these one-fifth are bluer than represented by *b*5. Moreover, we find no excessively large color indices, and none unusually small. A comparison of these colors with those derived by Parkhurst for bright stars near the north pole shows an entirely analagous distribution among the various classes. There seems to be no reason to doubt the present result, and we are left with the conviction that, so far as present data go, normal negative color indices exist in the Hercules cluster in large numbers. From the remarks of the preceding paragraphs it is at once obvious that such a condition could not co-exist with measurable selective absorption of light in space.

The distance of the Hercules cluster, we may be sure, is not less than

1000 units of stellar distance, and it may be nearly ten times this amount. If we were to adopt the value of the absorption constant derived by Kapteyn, then the smallest color indices in the cluster should be in excess of 2.5 magnitudes, and that for a star of spectrum M should be nearly five magnitudes. Actually not a single color index greater than two magnitudes has been observed. If we were to take Van Rhijn's value, the color indices in the cluster would all need to exceed a magnitude.

It seems to be necessary to conclude that the selective extinction of light in space is entirely inappreciable, at least in the direction of the Hercules cluster. If we grant, on the basis of our data, a color excess of a tenth of a magnitude, and attribute it all to space absorption, the value of the coefficient can not then exceed +0.0001 mag., an amount completely negligible in dealing with the ordinary isolated stars. In the light of this result we are probably justified in assuming that the non-selective absorption in space (obstruction) is also negligible.

The following references may be cited:

Newcomb, *The Stars*, chap. xiv, New York, 1902.
Turner, *London, Mon. Not. R. Astr. Soc.*, **69,** 61 (1908).
Kapteyn, *Astrophys. J.*, **29,** 46 (1909); **30,** 284, 316 (1909); **40,** 187 (1914).
King, *Cambridge, Mass., Ann. Obs. Harvard Coll.*, **59,** 182 (1912); **76,** 1 (1914).
Jones, *Observatory, London*, **37,** 402 (1914); *Mon. Not. R. Astr. Soc.*, **75,** 4 (1914).
Van Rhijn, *Dissertation*, Groningen, 1915.
Seares, These PROCEEDINGS, **1,** 481 (1915).

STUDIES OF MAGNITUDES IN STAR CLUSTERS, II. ON THE SEQUENCE OF SPECTRAL TYPES IN STELLAR EVOLUTION

By Harlow Shapley

MOUNT WILSON SOLAR OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

Received by the Academy, December 9, 1915

In many investigations of globular clusters the apparent magnitudes of the individual stars, which are the quantities observed directly, may be used without error as representing the absolute magnitudes. We may consider the stars in such a system to be at the same distance from the earth, and knowledge of that distance is unnecessary in discussing the relations between changes in the absolute luminosities of the stars and their colors or spectra.

If, as is most commonly believed, the evolution of the stars progresses, chiefly through the agency of condensation and cooling, from the bluer spectral types to the redder, then, since it is definitely known that the intrinsic surface brightness of the blue stars greatly exceeds that of the red, we should normally expect to find that all the bright stars in the